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STUDY OF WATER IN MALTING BARLEY DURING KILNING AND POST-KILNING STORAGE

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Study of water in malting barley during Kilning and post-kilning storage

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Abstract

During the malting process, kilning consumes the most energy. Kilning uses heated air, of which temperature and flow can be regulated, to dry the malt. However, air moisture level is not controlled. In wet weather it takes longer to dry the barley as the hot air used for drying already has high moisture content. This could cause excessive heating and result in colour and flavour problems. We propose to conduct a micro-malting study mimicking high humidity/high temperature conditions and examine the water distribution in the kernels over the drying process and in the final malt. These results will be compared to kilning at lower humidity and cooler temperature like the Prairie winter climate.

1 Technical Report

1.1 Background overview

Kilning, the final stage in the preparation of malt, represents a high cost, time-consuming factor for the malting plant. Kilning reduces the malt moisture level from 43% to 4% in a short period of time. Inhomogeneous drying of the kernel could cause storage problems, or unbalanced malt modification. Water movements in barley kernels during kilning will be non-invasively monitored by magnetic resonance imaging (MRI). Kilning is performed in two stages, the first one being at a temperature close to 50°C until the moisture level of the kernel drops from 43% to 23% and a second stage at higher temperature, 85°C, until moisture level in the kernel drops to 4%. Moisture level in the kilning air is critical and will influence kilning time, therefore could also affect brewing quality of the malt produced.

1.2 Summary of Research Progress

During the third year of the project, we were able to meet the following milestones:

i) Three micro-malting tests were completed at the University of Saskatchewan laboratory with low, medium, and high settings for relative humidity and temperature, respectively.
ii) Moisture migration patterns were documented by MRI, in relationship with three different malting conditions.
iii) Correlation between malt analysis parameters, and the malting conditions were established.

1.3 Experimental

1.3.1 Micro-malting

Micro-malting experiments were performed on an automatic micro-malting system of Phoenix Systems Inc., Kingswood, Australia, at the Department of Plant Sciences of the University of Saskatchewan. After consultation with collaborators at Prairie Malt Ltd., a malting cycle, as shown in Figure 1, was selected for the experiments. The total duration of the malting cycle was 157 hours. Micro-malting experiments were performed on batches of 50g of Harrington barley per run. The micro-malter is equipped with cylindrical drums which could contain up to 100g of barley. Running batches of 50g was made possible through the use of a drum divider. The malting program started with a succession of steeping and air rest periods of 2 hours each. Steep number four was followed with an 89 hours germination period. After germination starts the kilning stage. First step of the Kilning stage is to gently dry the kernels down to 25% moisture at 49°C. Then temperature is increased step by step to 85°C to dry the kernels to 4% moisture. The efficiency of the first kilning stage at 49°C would be affected by high air moisture, therefore limiting the drying ability of warm air and extending the drying time. To simulate high air moisture levels during the kilning stage, the built-in features of the Phoenix micro-malter did not allow to keep high moisture for a long time. A humidifier has been designed to fit in, at the hot air input, and bring up the kilning air moisture level. It was chosen to run experiments with 35% and 45% air moisture levels to see how it affects drying of the kernels. After the full malting program was completed, a malt quality evaluation was performed on 22 malt samples after each run. This evaluation was performed using wet chemistry with an auto-analyser.

1.3.2 NMR Experiments

The studies described in this research were performed on a Bruker Avance 360 MHz DRX NMR system, specially equipped to perform micro-imaging experiments on solid materials such as seeds. Micro-imaging experiments were performed at room temperature (20°C) on single seeds mounted in a shortened pipette tip inserted in a Plexiglas foot and then inserted in a 10 mm NMR tube using a Bruker Micro-2.5 micro-imaging probehead and gradient system. Each seed was oriented by the same procedure to allow identical image slice positioning.
For the acquisition of micro-images a spin-echo pulse sequence was used (MSME-MOD). Each echo experiment took 17 minutes for 4 scans and used a Field of View

(FOV) of 1.5 cm and a slice thickness of 1.0 mm. Each image consisted of a 256 x 256 data matrix, resulting in a pixel resolution of 59 um. This resolution is more than sufficient to follow water uptake in the different tissues/compartments of barley kernels. The MSME-MOD spin echo pulse sequence consisted of 2 ms SINC3 pulses for selective excitation and refocusing and an echo time of 10.1 ms., using a sweep width of 50 kHz.

1.4 Results

1.4.1 Micro-malting

A first set of three experiments, with respectively room moisture (15%), 35% moisture and 45% moisture was done. Grain moisture was monitored during the experiments with grain weight measurements (Figure 2). The three curves obtained show the slower drying of the grain. The critical 25% grain moisture stage was reached after 22 hours with 35% kilning air moisture and after 33 hours with 45% kilning air moisture. A second set of similar experiments was designed in order to document water movements in the grain under the three different conditions. MRI was done for each experiment at 4 different stages (Table 1): – high grain moisture (47-50%) – intermediate grain moisture (38-43%) – 22% grain moisture – below 15% grain moisture.

1.4.2 ^{1}H Micro-imaging studies

Figure 2 shows a simple model of a barley kernel in a reference frame. Images shown in this report are taken in the XY plane. Images are displayed using a false colour scheme. Images of hydrated seed show water signal intensity to vary from red (high moisture) to yellow, green, blue, purple and black (very low or lack of moisture).
For each malting experiment, MRI was performed on two kernels at every sampling time (figures 4, 5 and 6). No obvious difference is showing for the three experiments at either high moisture content or 22% and lower. The differences in water repartition in the grain appear at intermediate moisture content. Water concentrates and stays longer in the median area of the kernel, below the transversal crease.
From these images, it can be seen that at high RH, the acrospire grows drastically during the early stages of kilning (15hrsA, 15HrsB @45RH). This can cause substantial malting loss and over modification of the malt, if the germination prior was not restricted. Most of the moisture in the malt is concentrated in the areas of the embryo and the acrospire, where the biological activity is the highest. These suggest the importance of a prediction of the kilning conditions and feedback to decide when to switch from germination to kilning. The higher the potential RH, the earlier the switch over of program should take place. Such forecast and feedback system should be taken into consideration when control systems for malting processes are designed.

1.4.3 Wet Chemistry evaluation of malting quality

Wet chemistry analysis of malted barley was performed on 22 samples after each run. Results in table 2 show a trend to lower protein content, lower β–glucan and higher friability with the increasing moisture in the kilning air. These experiments allowed a longer kilning time to dry the grain properly, therefore allowing additional modification of the malt. The rate of grain moisture change is very much dependent on the relative

humidity (RH) of the ambient kiln air, as indicated in Fig 2. As the RH increases from 15% to 45%, the total time required to dry the grain down to 20-22% was more than doubled. Biochemical on one hand, higher RH gives the grain more time to degrade the components at warm conditions, which results in the observed lower beta-glucan, higher extractable matters, and higher friability. This indicates that when the RH is high, we can proportionally reduce the germination time and the following kilning process will compensate the malt modification. On the other hand, longer kilning time due to high RH, will consume more energy to dry down the malt to required moisture. Therefore, there might be a process, with less energy consumption, to remove the moisture in air to reduce the RH of the ambient air before entering to kiln. More importantly, this RH treatment of kilning air will also result in more consistent malt quality. The industry will have to analyze and balance the scenarios in order to optimize the process and save energy cost.

2 Personnel

Michael Bateman, Technical Research Assistant
Eric Lefol, Professional Research Associate

3 Equipment

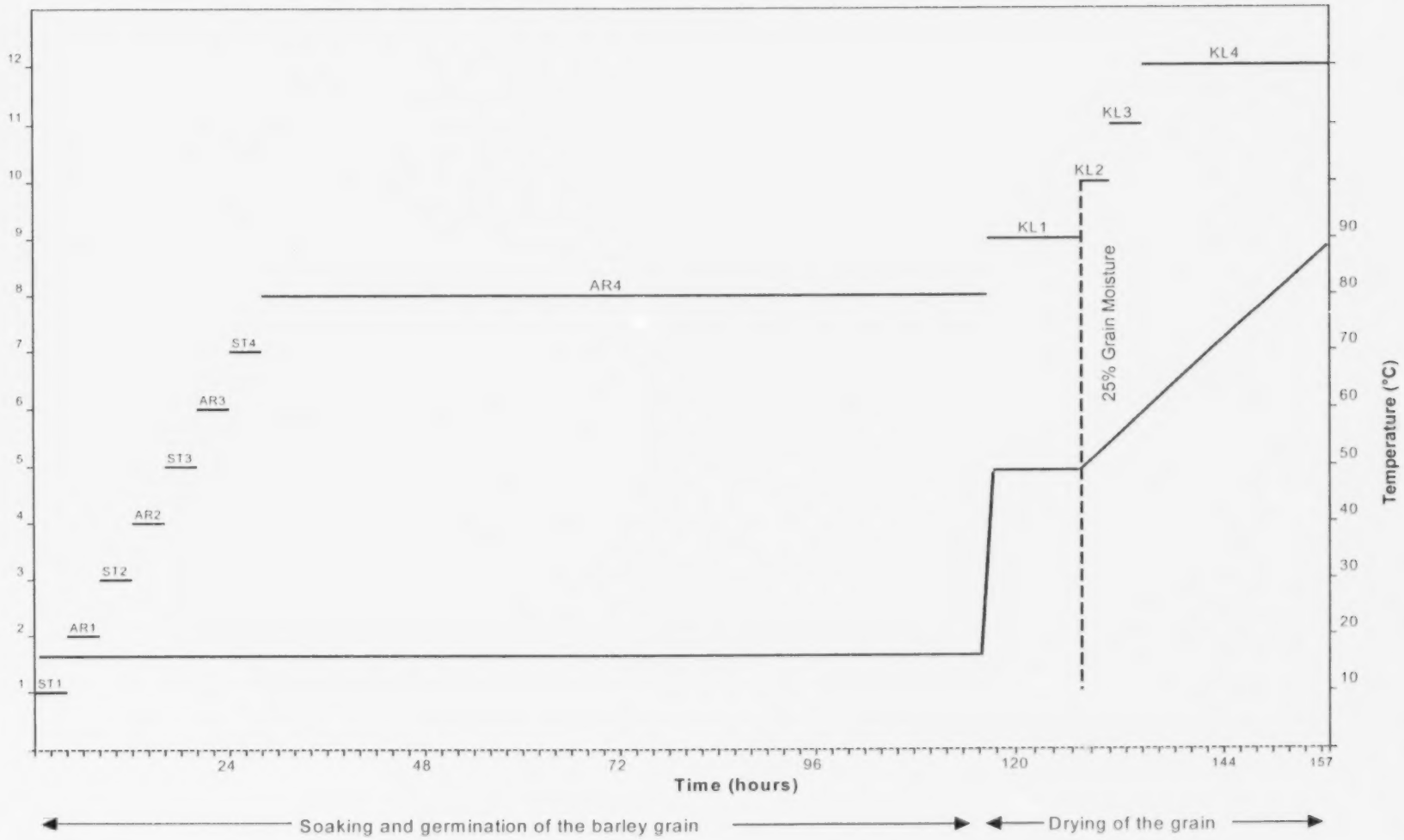
Item	Price ($)
Variable Flow pump	201.57
Plastic ABS + Intecell	211.94
Insulation, Glue, Ducts	57.35
Screen	8.21
Tubing, Valves	34.32
Valves, Sleeves	18.60
Misc. Supplies	17.72
Shop labor, 14 hours at $60.00 per hour	840.00
Total	**1389.71**

4 Acknowledgements

Support from the Agricultural Development Fund (ADF) has been acknowledged during tours of visitors to the NMR/MRI facilities.

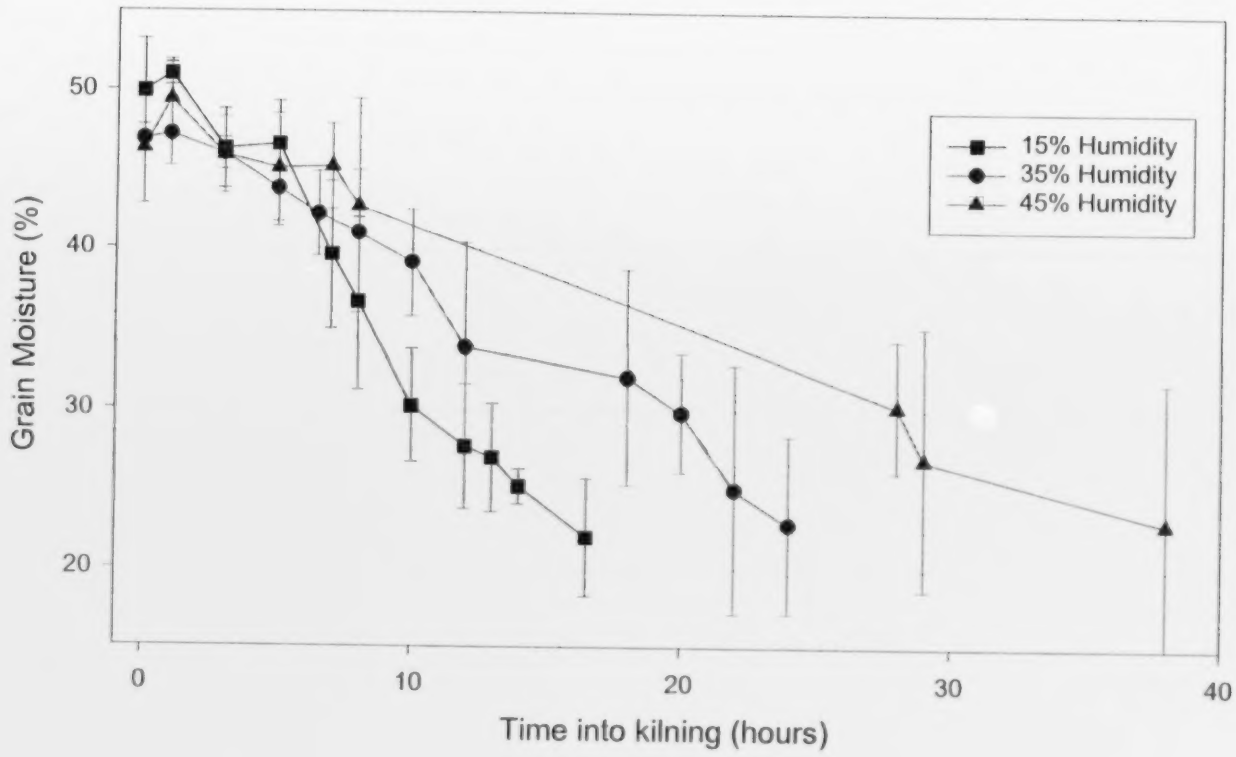
ANNEXES:

Fig. 1: Standard Malting Barley Schedule



Note: **ST** = Steeping, **AR** = Air rest, **KL** = Kilninig

Fig. 2: Grain moisture decrease under three kilning conditions



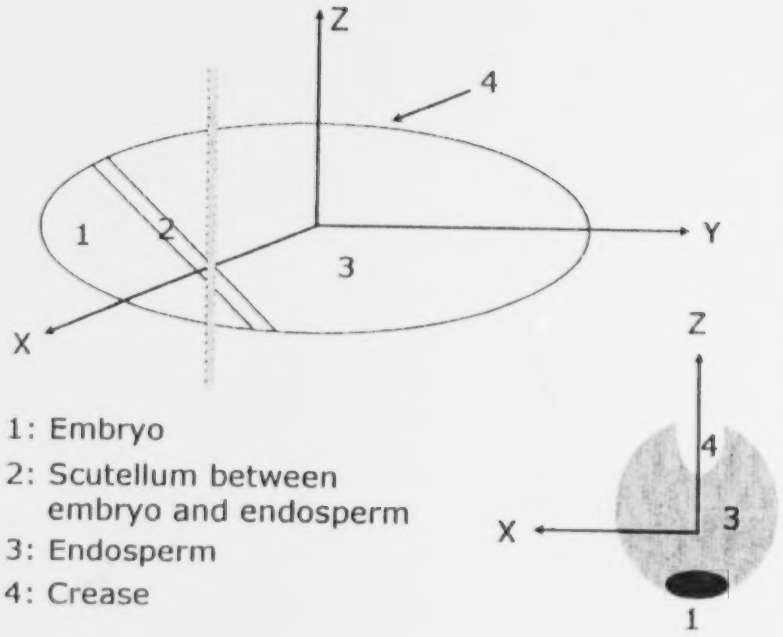


Fig. 3: Very simple model of a barley kernel indicating the positions of the embryo and crease. An axis-system has been inserted to use as a guide for the interpretation of the MR images.

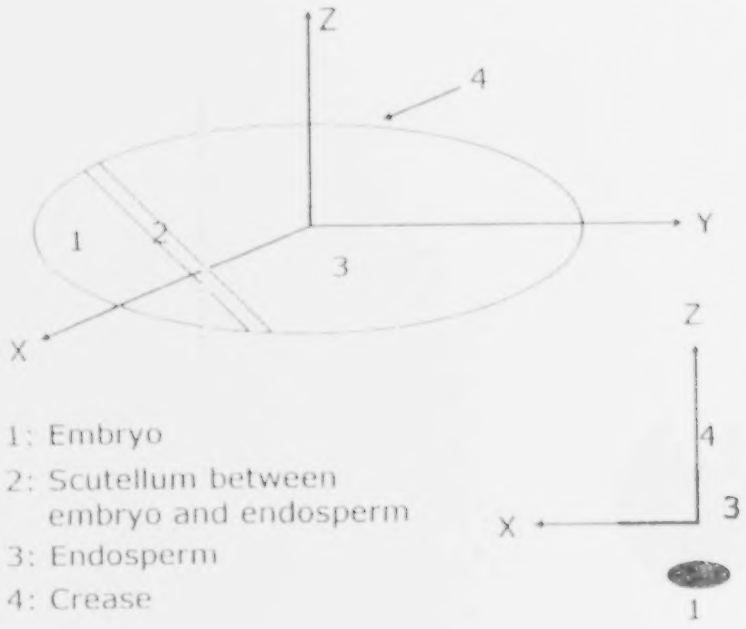


Fig. 3: Very simple model of a barley kernel indicating the positions of the embryo and crease. An axis-system has been inserted to use as a guide for the interpretation of the MR images.

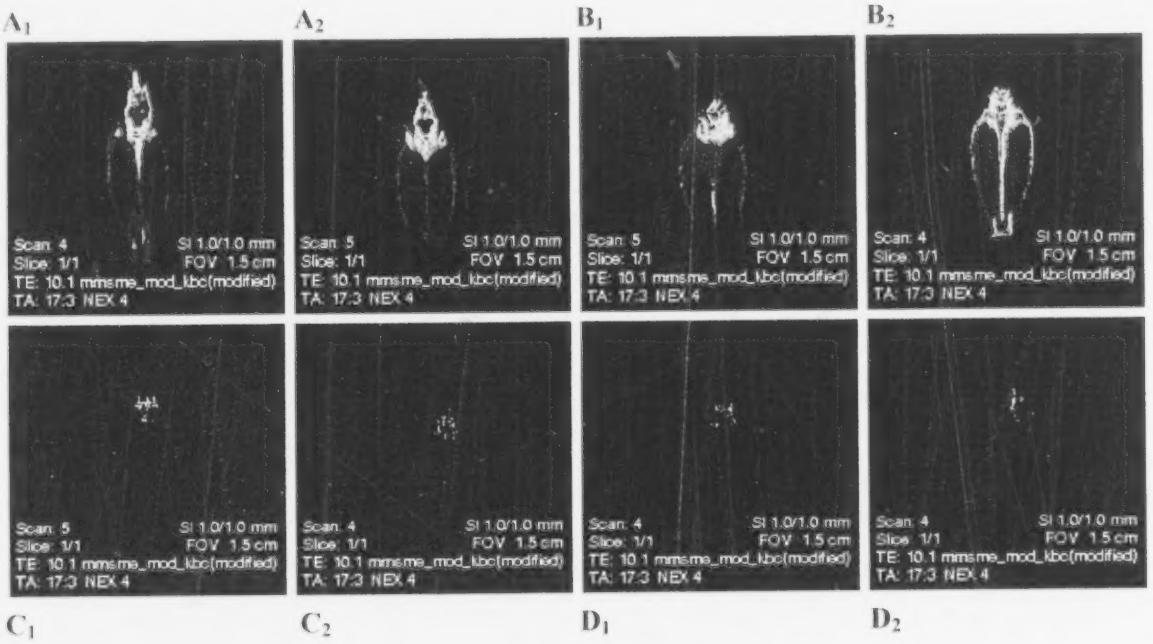


Fig 4: 15% Moisture Level

$A_{1,2}$ 0 hrs.
$B_{1,2}$ 6 hrs.
$C_{1,2}$ 16 hrs.
$D_{1,2}$ 24 hrs.

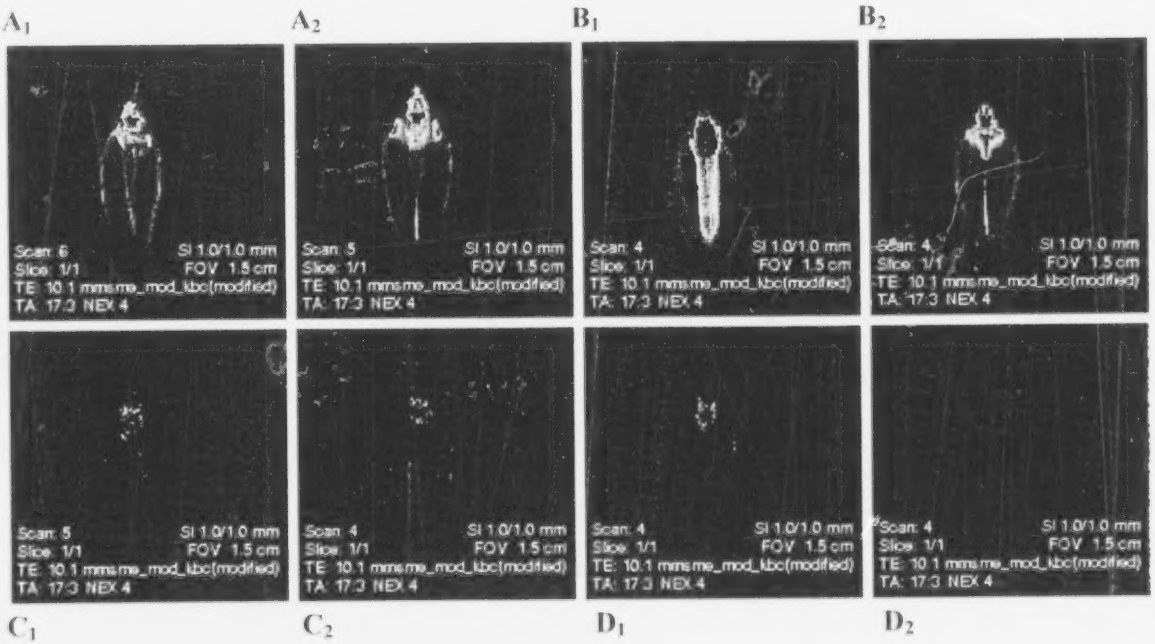


Fig 5: 35% Moisture Level

$A_{1,2}$ 0 hrs.
$B_{1,2}$ 7 hrs.
$C_{1,2}$ 28 hrs.
$D_{1,2}$ 34 hrs.

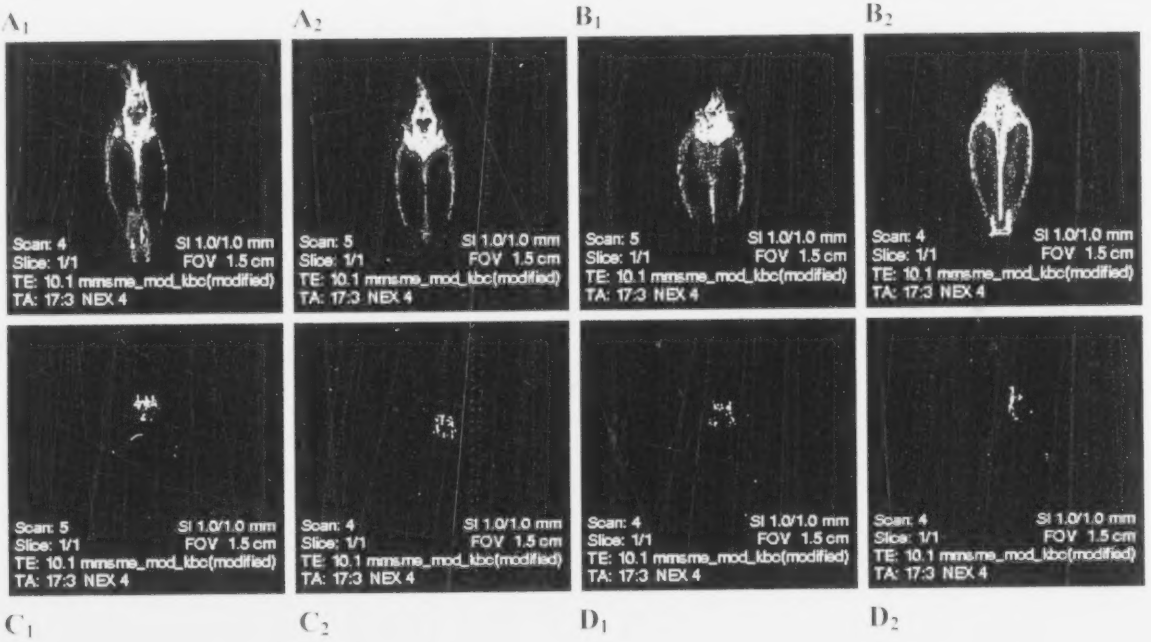


Fig 4: 15% Moisture Level

$A_{1,2}$ 0 hrs.
$B_{1,2}$ 6 hrs.
$C_{1,2}$ 16 hrs.
$D_{1,2}$ 24 hrs.

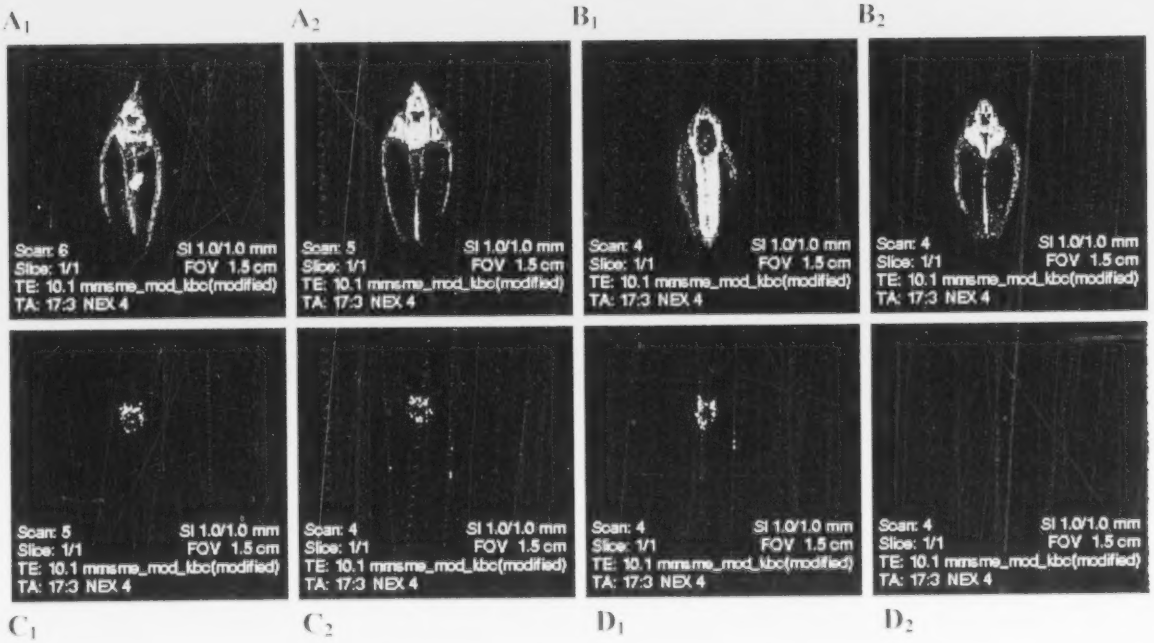


Fig 5: 35% Moisture Level

$A_{1,2}$ 0 hrs.
$B_{1,2}$ 7 hrs.
$C_{1,2}$ 28 hrs.
$D_{1,2}$ 34 hrs.

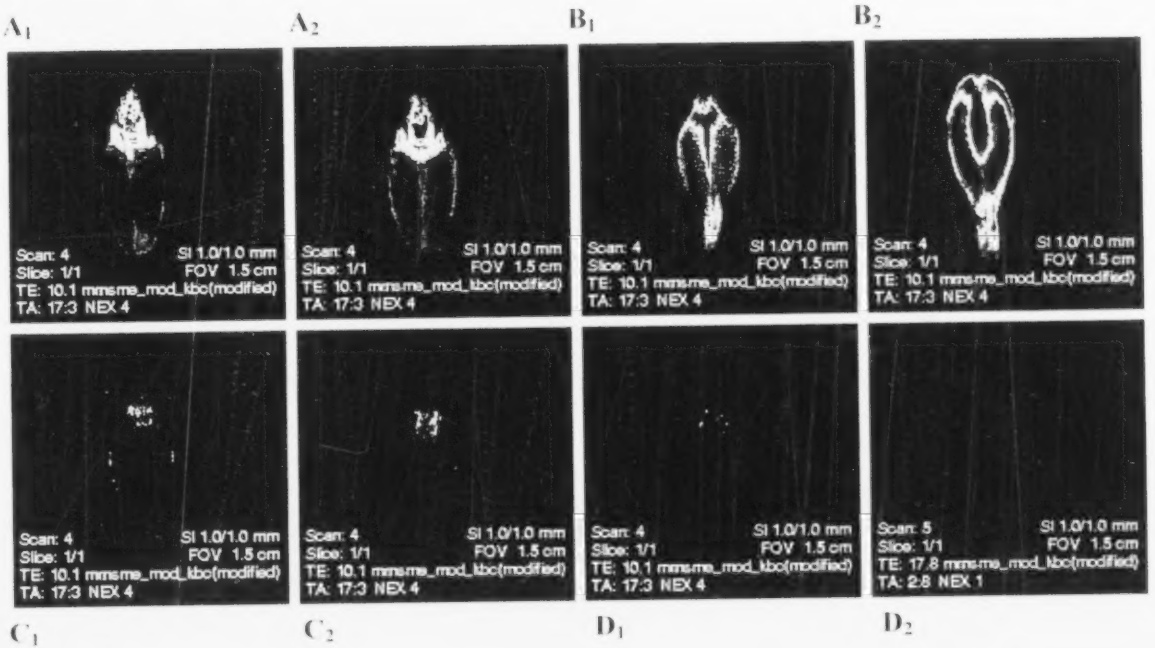


Fig 6: 45% Moisture Level

$A_{1,2}$ 0 hrs.
$B_{1,2}$ 15 hrs.
$C_{1,2}$ 39 hrs.
$D_{1,2}$ 44 hrs.

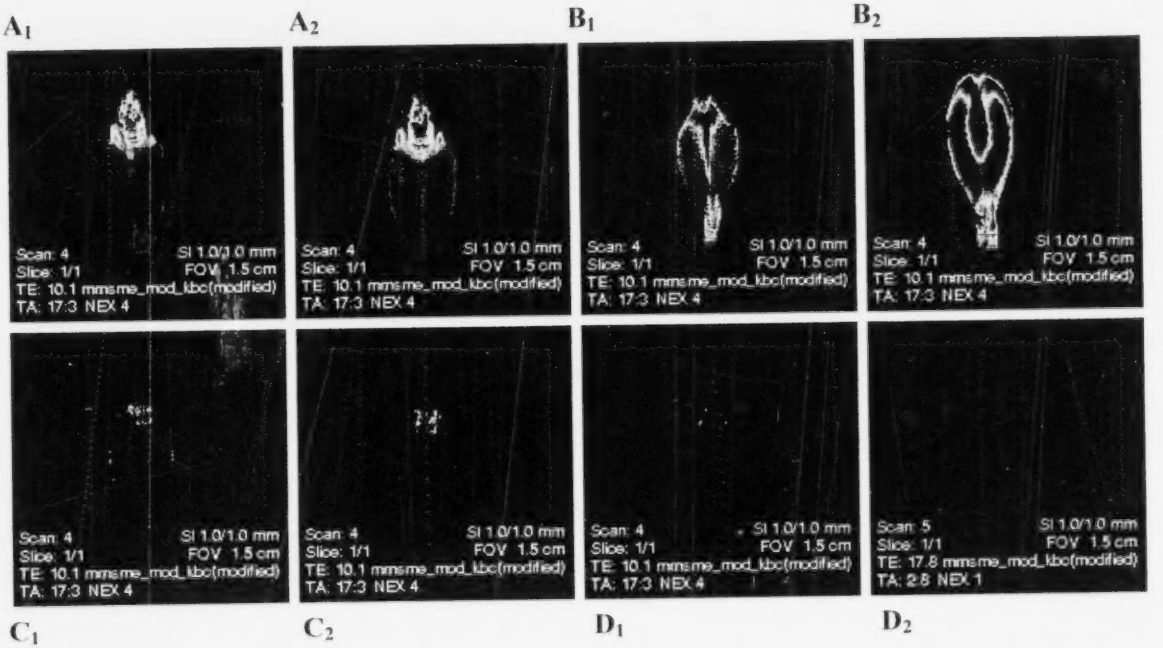


Fig 6: 45% Moisture Level

$A_{1,2}$ 0 hrs.
$B_{1,2}$ 15 hrs.
$C_{1,2}$ 39 hrs.
$D_{1,2}$ 44 hrs.

Table 1: Sampling time for micro-imaging of barley kernels
(hours into kilning)

Grain Moisture	Kilning air moisture 15%	35%	45%
47-50%	0 hr	0 hr	0 hr
38-44%	6 hrs	7 hrs	15 hrs
22%	16 hrs	28 hrs	39 hrs
below 15%	24 hrs	34 hrs	44 hrs

Table 2: Malting Quality evaluation. Highlighted numbers are averages of 22 evaluations performed on radomly picked malt samples.

Air moist		T.P. %	Moisture %	α-amylase D.U.	Extract %	ß-glucan p.p.m.	D.P. °L	Friab. %
	MIN	10,37	3,74	31,19	6,95	0,17	32,14	74,30
	MAX	11,92	4,87	48,91	64,69	0,32	42,63	93,80
Reg	AVG	11,46	4,51	37,08	60,53	0,22	36,87	82,44
	STDV	0,35	0,24	4,78	11,48	0,04	2,76	3,63
	MIN	10,97	4,44	21,28	60,26	0,17	36,49	79,30
	MAX	12,05	5,19	36,27	67,37	0,29	39,52	89,20
35%	AVG	11,48	4,82	29,92	62,97	0,22	38,87	82,18
	STDV	0,28	0,18	3,55	1,53	0,03	0,81	2,18
	MIN	10,13	3,08	24,80	61,93	0,11	34,00	84,90
	MAX	11,66	4,32	42,41	66,57	0,15	40,13	96,50
45%	AVG	**10,72**	3,77	34,25	63,94	**0,13**	36,83	**91,84**
	STDV	0,28	0,31	4,16	1,16	0,01	2,00	3,39